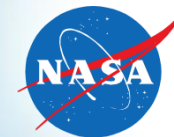


National Aeronautics and Space Administration



Engine Icing Performance Simulation

Philip C. E. Jorgenson
Aerospace Engineer, Turbomachinery and Heat Transfer Branch

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www.nasa.gov



Outline

- Background
- Approach
- Results
- Summary and Conclusions

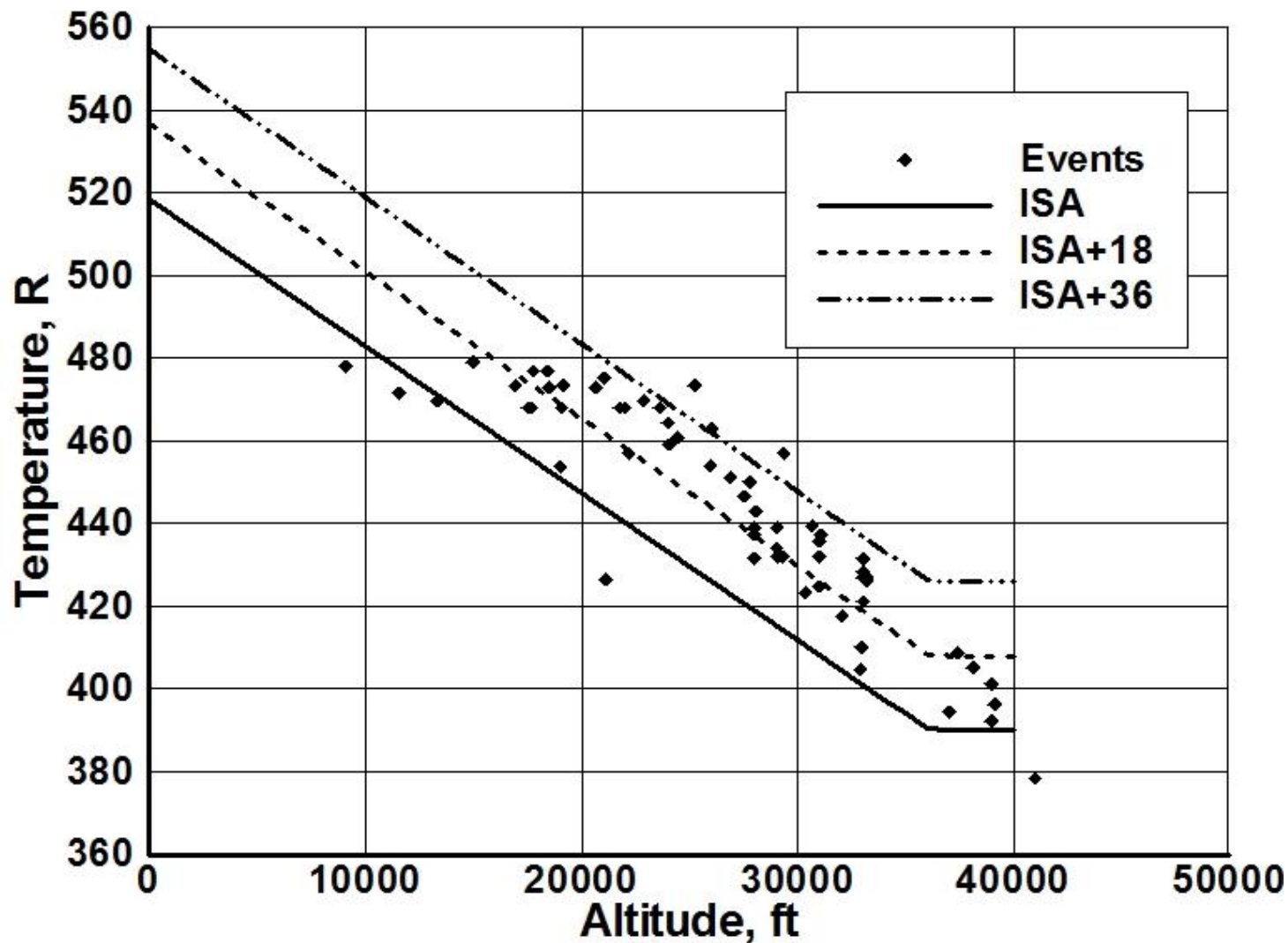


Background

- Commercial Airlines have reported ice accretion events that have resulted in degraded engine performance in the form of engine roll back, compressor surge and stall, and even flameout of the combustor.
- Ice crystals are ingested into the engine low pressure compression (LPC) system, the air temperature increases and a portion of the ice melts allowing the ice-water mixture to stick to the metal surfaces of the engine core.
- There is a lack of computational tools that can predict the occurrence of ice accretion and its effects on the LPC and the engine system performance at altitude conditions.



Reported Engine Icing Events with ISA and Elevated Temperatures (+18, +36)





Approach

- Leverage from existing computational tools to simulate engine and compressor aerothermodynamic performance:
- NPSS - Numerical Propulsion System Simulation advanced thermodynamic code written in an object-oriented language for system modeling of gas turbine engines. Provides component level analysis.
- COMDES - a design and analysis mean line compressor flow code that provides detailed flow conditions between blade rows, velocity triangles, and overall performance.
- Couple the NPSS and COMDES codes such that they run concurrently, exchanging BCs at each operating point.
- NPSS-COMDES will produce the flow field through the fan-core and LPC along the flight trajectory. The flow field will be provided as BCs for subsequent analysis for ice accretion using GlennICE.



Approach (Continued)

- Run the engine system code and the compressor analysis code concurrently such that blade-row to blade-row flow conditions can be computed along the flight trajectory.
 - Compute a baseline solution over a notional flight trajectory
 - Determine potential locations within the LPC where local flow conditions are favorable for ice accretion, initially based on static temperature.
 - Perform a parametric sensitivity analysis of ice blockage over the complete flight trajectory with the mean-line compressor analysis code coupled to NPSS, increasing the blockage within certain blade rows.
 - Analyze the fan-LPC in the engine systems environment. The analysis code coupled with NPSS effectively replaces the component (LPC) performance maps.



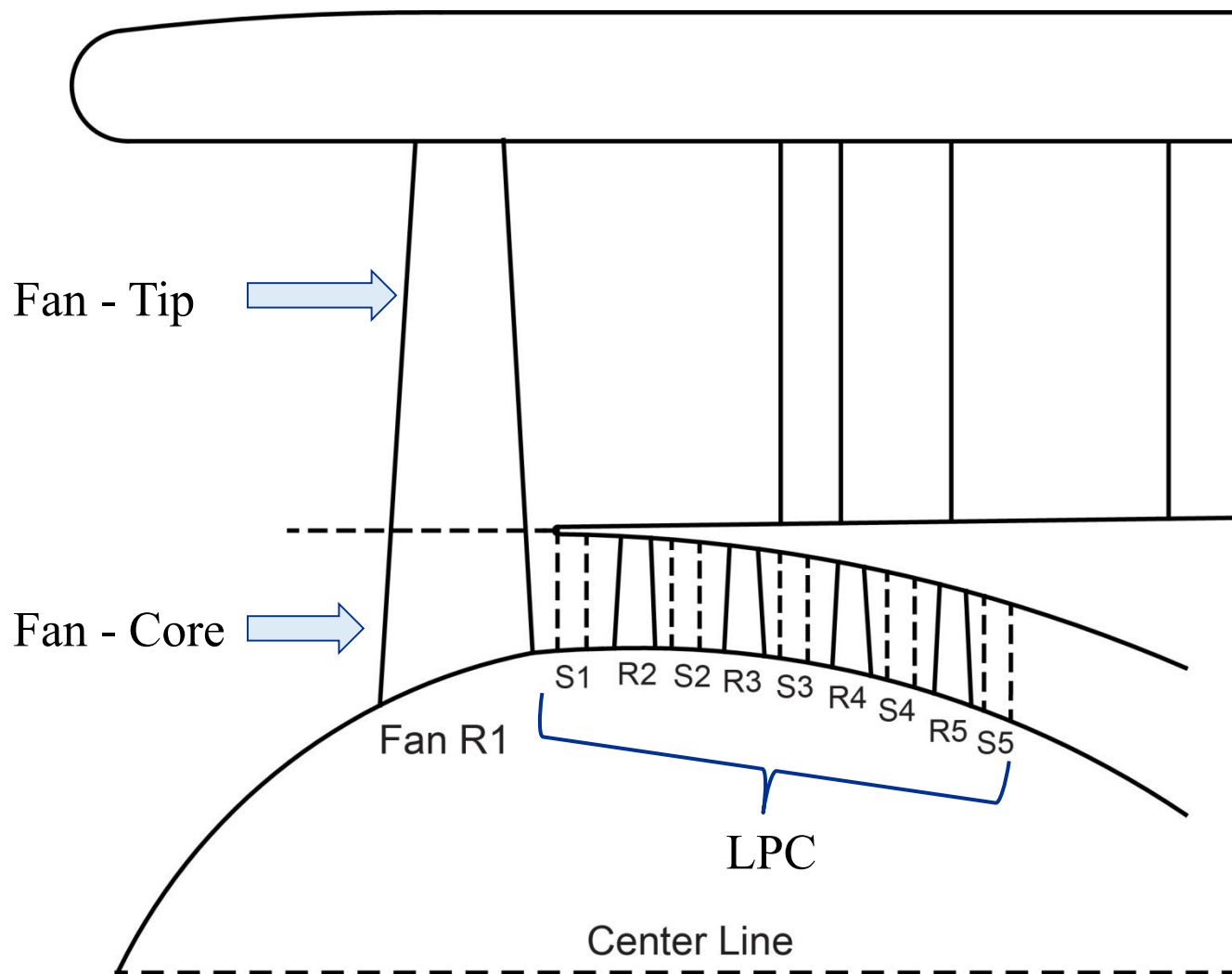
Approach (Continued)

- Lack of publicly available, non-proprietary engine geometry and performance data, necessitated a notional 40K lbf thrust class engine to be utilized for this study.
 - Conceptual design of fan and LPC was performed, since details were needed for the COMDES mean line flow analysis.
 - Produce a baseline performance map and superimpose the selected engine operating points through the flight trajectory, including cruise and descent.
- A temperature range where ice could accrete was initially assumed to be within a static temperature range of 509-515R, based on data in the literature.
- Currently NPSS and compressor flow analysis codes assume no humidity or ice / water in the flow.
- Parametric study of blockage in LPC stators currently assumes constant max thrust at each operating point.



Fan-Core and LPC Cross Section of 40K Thrust Class

Based on Conceptual Design with COMDES



Fan and LPC Design Point Objectives at Sea Level Takeoff

<i>Fan - Tip</i>	
Flow, lbm/sec	1122
Pressure Ratio	1.701
Efficiency	91.1
Shaft Speed, RPM	3761.1
<i>Fan - Core & LPC</i>	
Flow, lbm/sec	172
Pressure Ratio	2.23
Efficiency	87.0
Engine Bypass Ratio	5.8



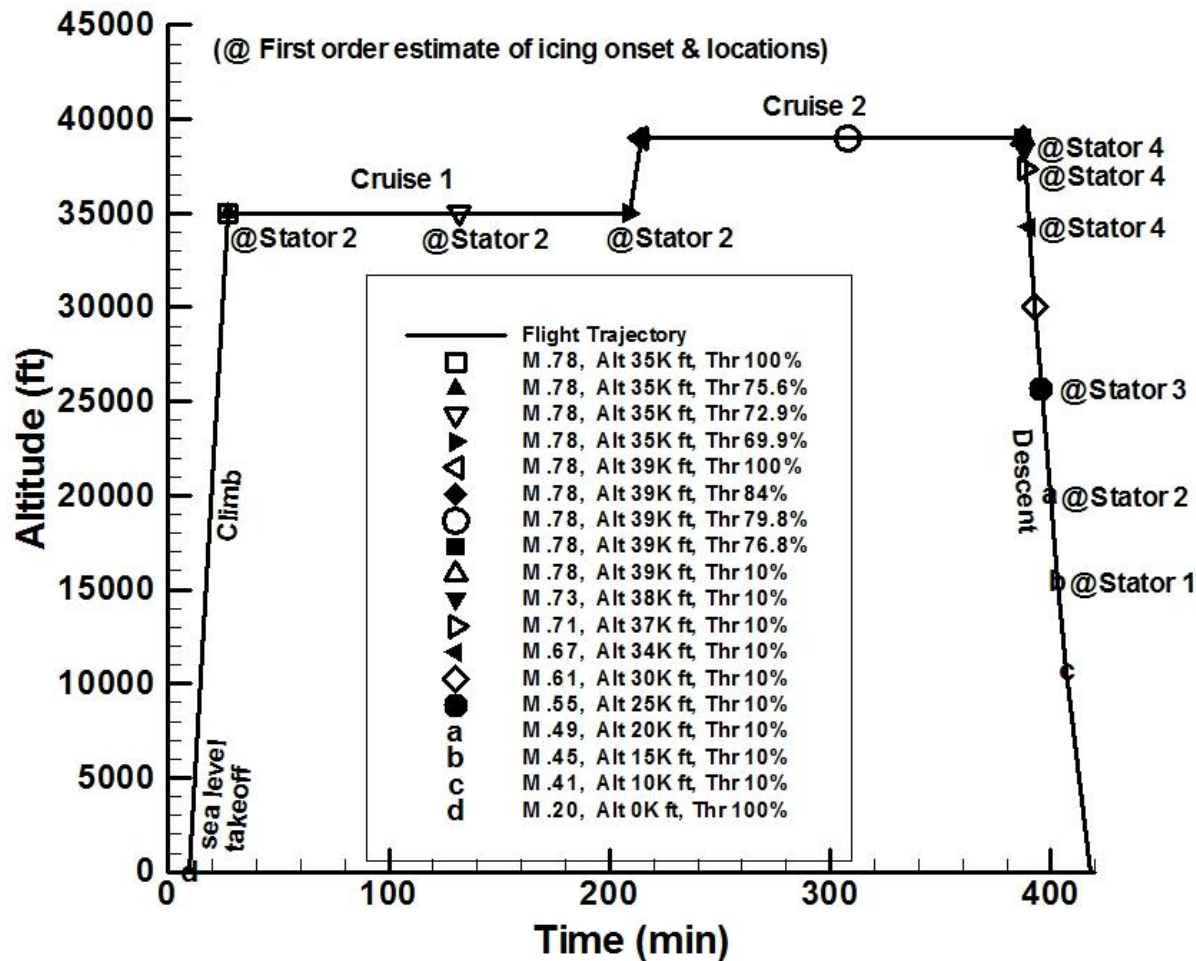
Fan-Core and LPC Design Point Geometric and Aerodynamic Parameters

	Fan-Hub Rotor1	Fan-Hub Stator1	LPC Rotor 2	LPC Stator 2	LPC Rotor3	LPC Stator 3	LPC Rotor 4	LPC Stator 4	LPC Rotor 5	LPC Stator 5
Leading Edge										
Press Stat., psia	13.67	14.67	16.61	18.785	20.12	22.45	23.91	26.41	27.88	30.04
Temp Static, R	508.0	522.1	542.22	564.55	576.56	597.76	609.40	629.48	640.0	656.21
Mach no., abs	0.38	0.638	0.46	0.534	0.42	0.499	0.39	0.449	0.34	0.417
Blade Angle	47.20	35.4	42.3	30.6	23.5	31.5	43.80	32.4	44.80	33.0
Abs Flow Angle	0	36.15	0	31.22	0	32.18	0	33.00	0	0
Tip Radius, in.	20.63	20.6171	20.5304	20.3433	20.0960	19.6905	19.3131	18.8420	18.2524	17.6890
Hub Radius, in.	12.51	15.1021	15.2113	15.2026	15.0546	14.8484	14.3197	13.7204	13.0749	12.2606
Trailing Edge										
Press Stat., psia	14.69	16.35	18.76	19.79	22.40	23.56	26.19	27.53	30.06	31.22
Temp Static, R	521.86	539.72	563.96	573.81	597.00	606.82	627.60	637.69	655.84	663.90
Mach no, abs.	0.63	0.481	0.53	0.448	0.49	0.413	0.46	0.368	0.41	0.338
Blade Angle	12.7	0	23.5	0	23.5	0	23.5	0	23.5	0
Abs Flow Angle	36.93	0	31.59	0	32.30	0	32.27	0	33.24	0
Tip Radius, in.	20.63	20.5733	20.4459	20.1704	19.9256	19.4117	19.0737	18.4850	17.9280	17.2148
Hub Radius, in.	15.0	15.1901	15.2230	15.2026	14.8484	14.4742	13.9111	13.2848	12.4811	11.6228

Sea level takeoff conditions

Notional Flight Trajectory

Ice Accretion Estimation Based on the NPSS – COMDES Analyses

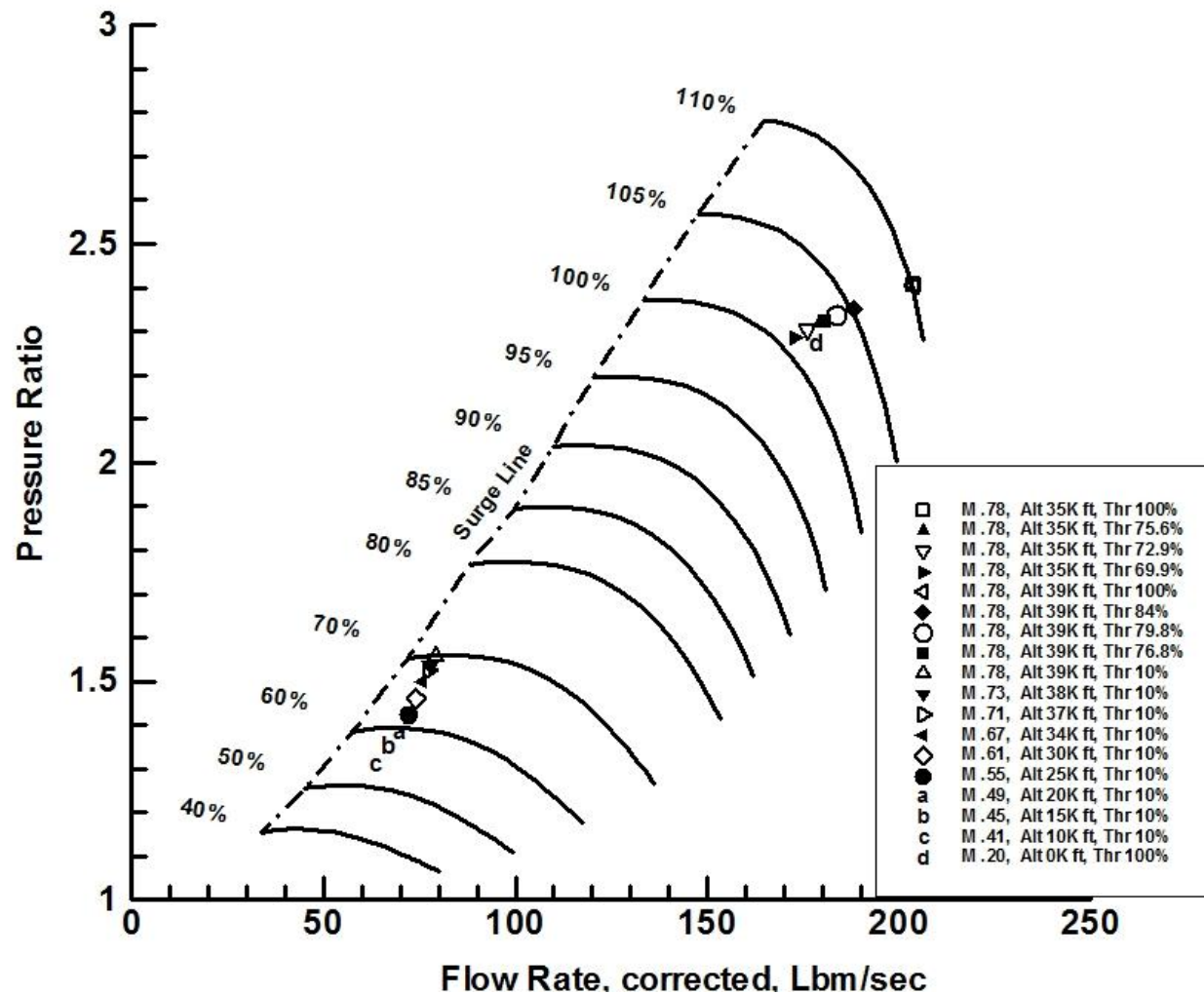


Assumptions:

- Assumed temperature range where accretion occurs: 509-515 R
- Icing occurs in the fixed components only (stators).



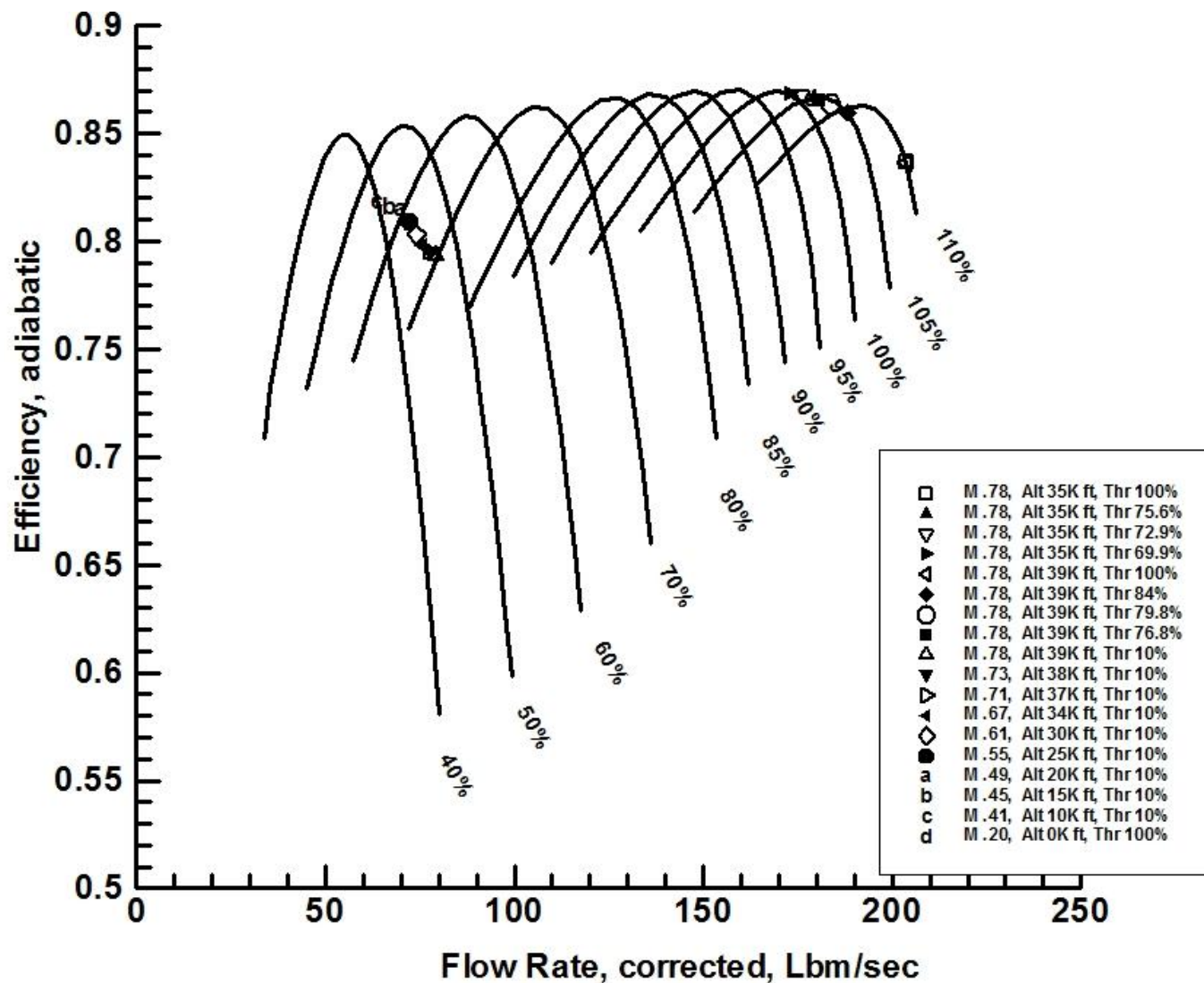
Baseline Fan-Core and LPC Pressure Ratio Performance Map



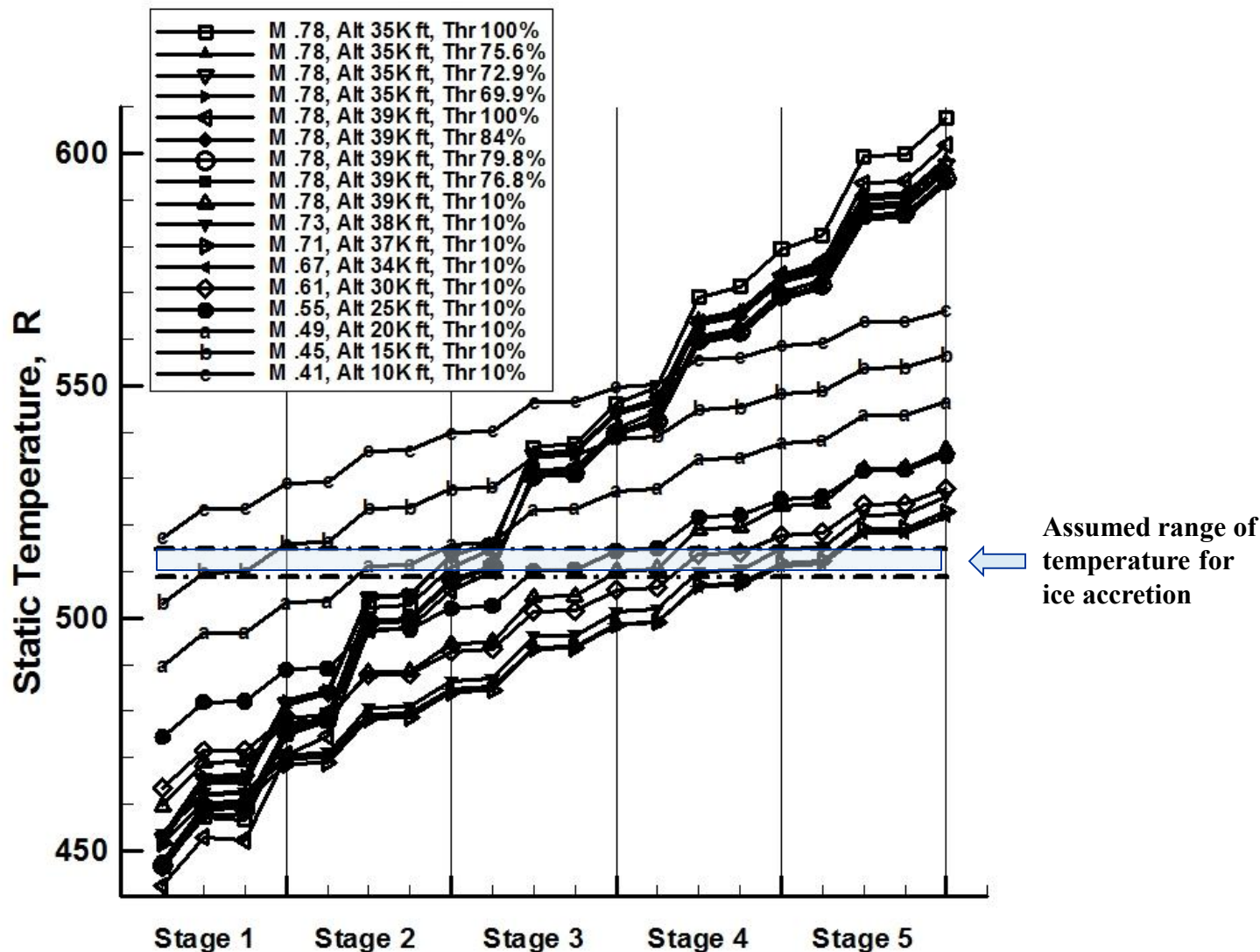
Operating points over the flight trajectory plotted on baseline performance map



Baseline Fan-Core and LPC Efficiency Performance Map

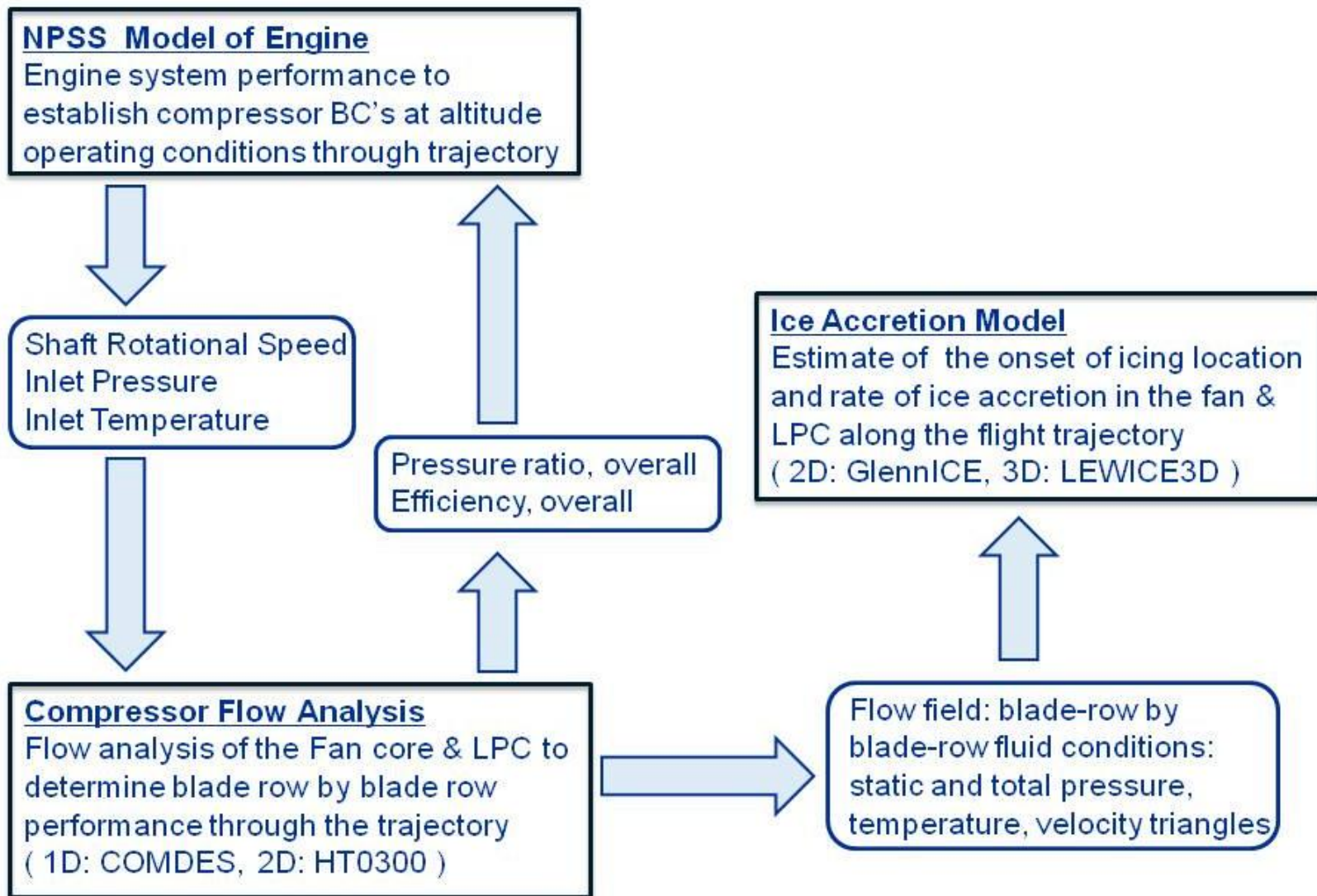


Static Temperatures in LPC through Engine Flight Trajectory

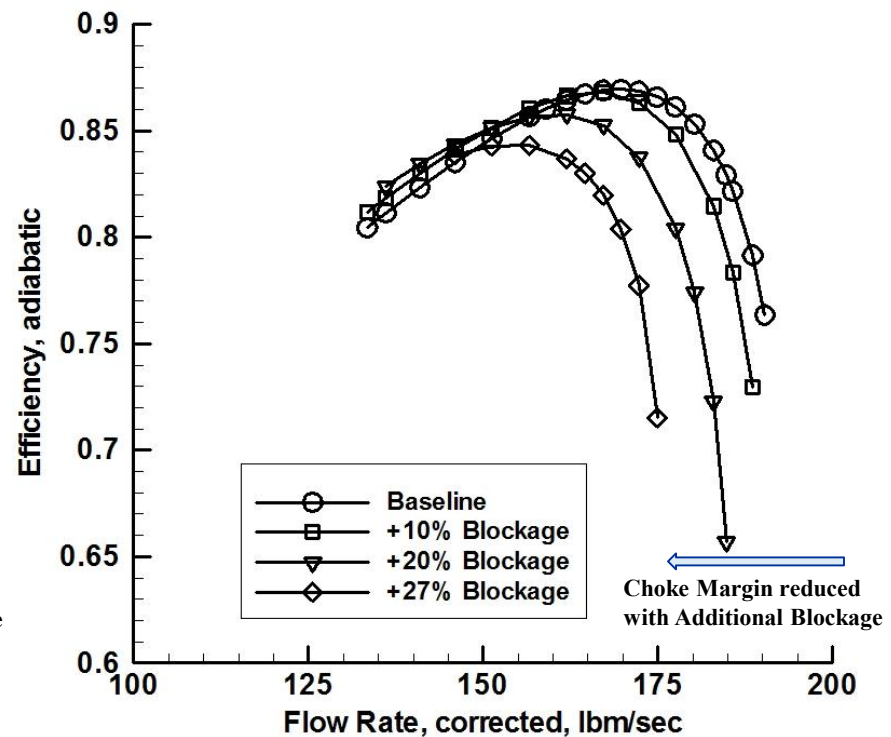
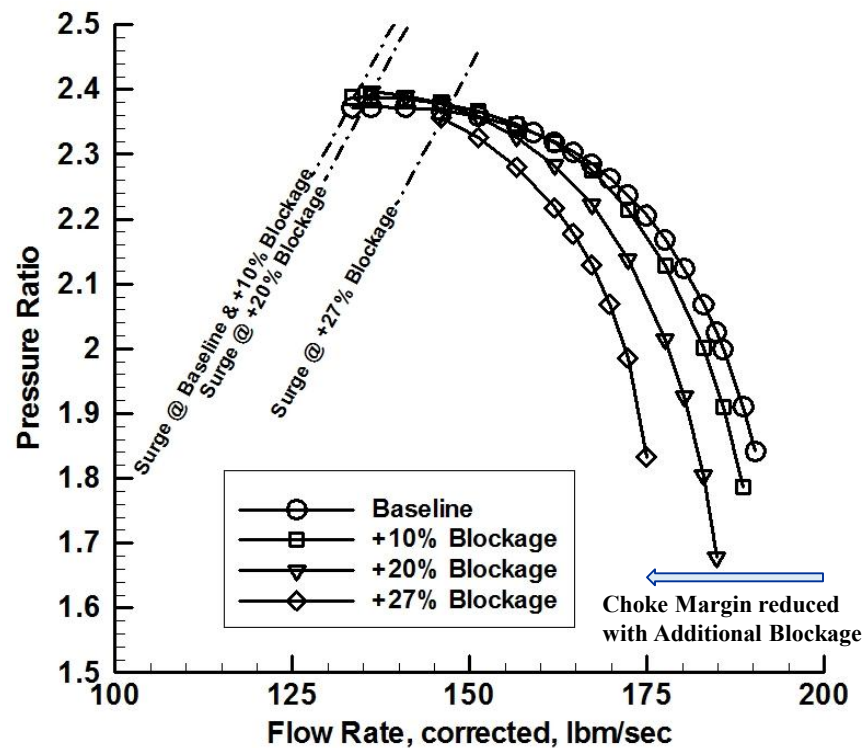




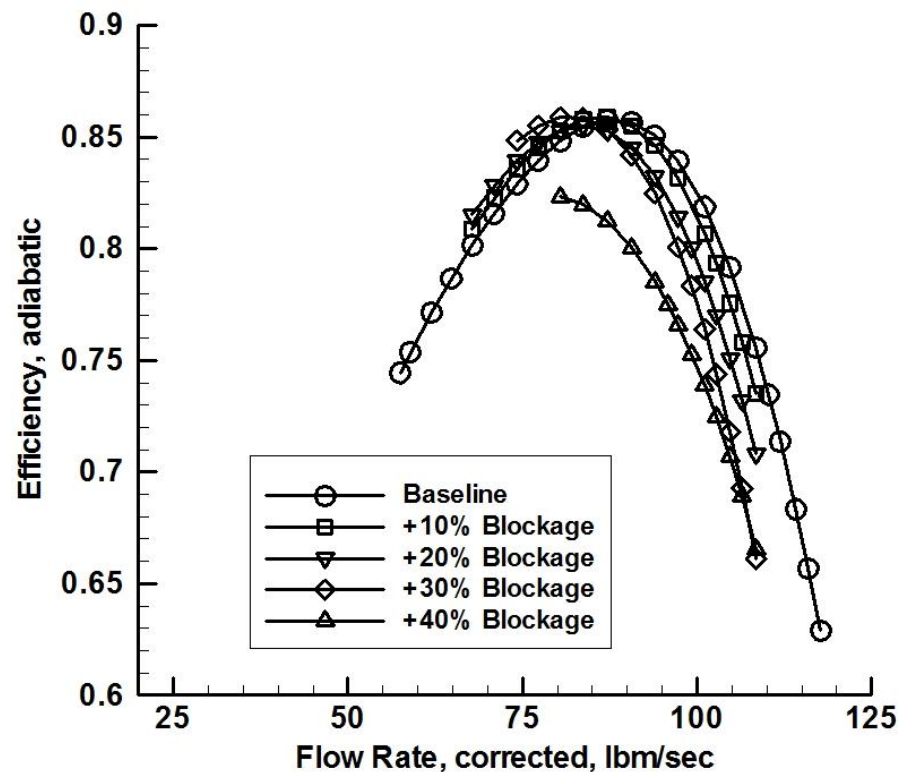
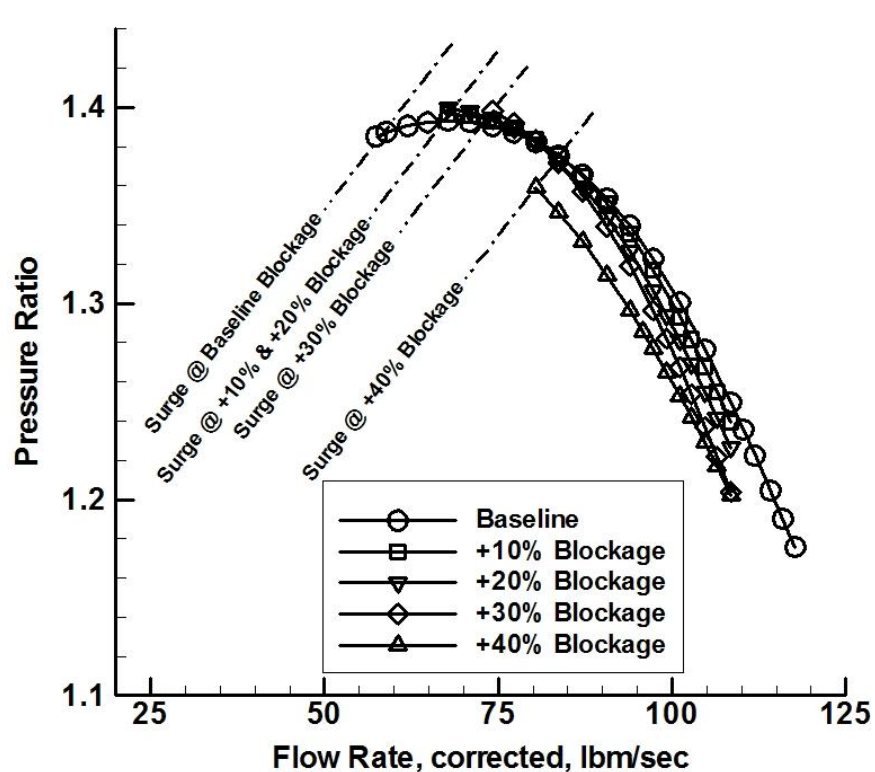
Tools for Estimating Engine and Detailed LPC Performance Through Vehicle Flight Trajectory



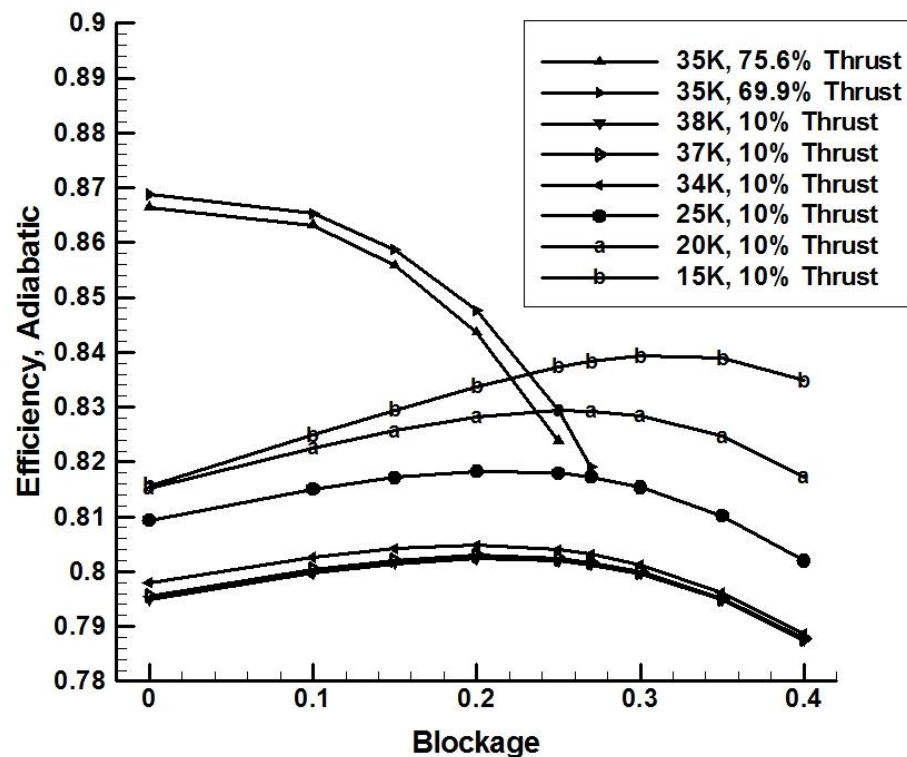
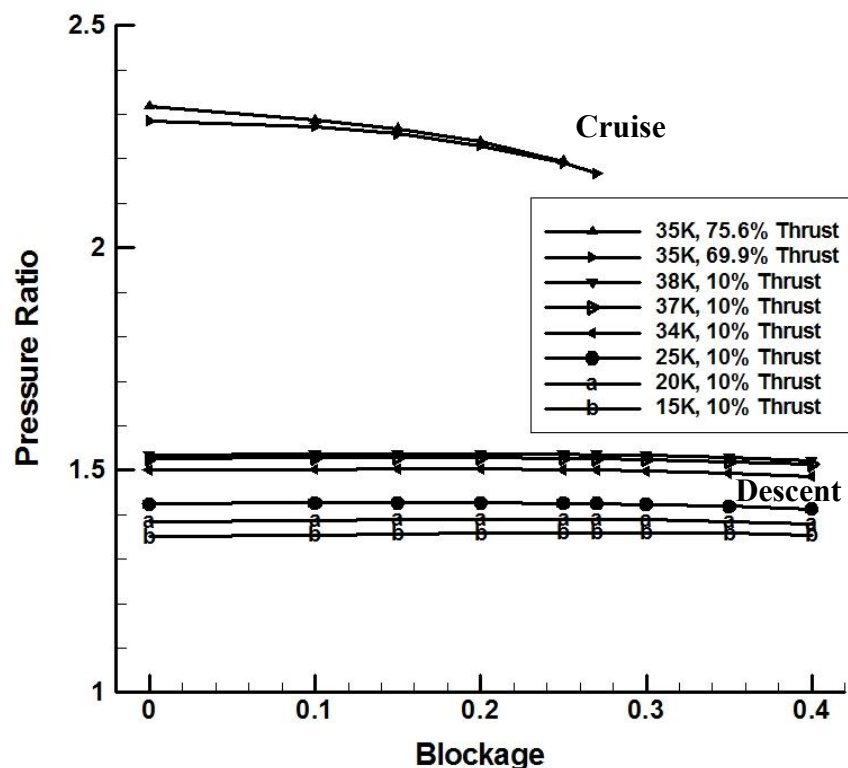
Overall Pressure Ratio and Efficiency at 100% Speed Line vs. Additional Blockage in Stage 2 Stator of LPC



Overall Pressure Ratio and Efficiency at 60% Speed Line vs. Additional Blockage in Stage 2 Stator of LPC

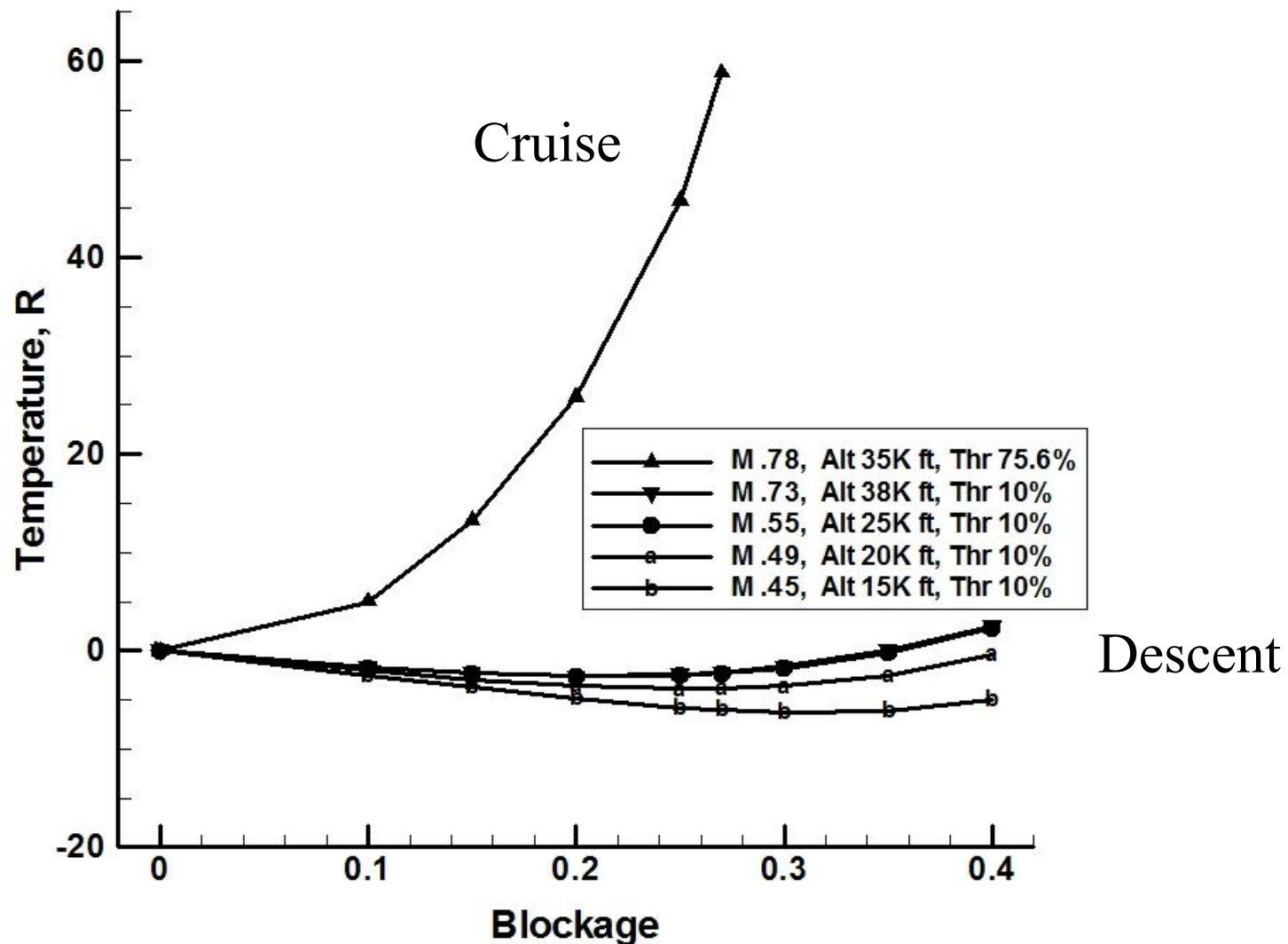


Effects of Additional Blockage on Overall Fan-Core and LPC Pressure Ratio and Efficiency along Flight Trajectory





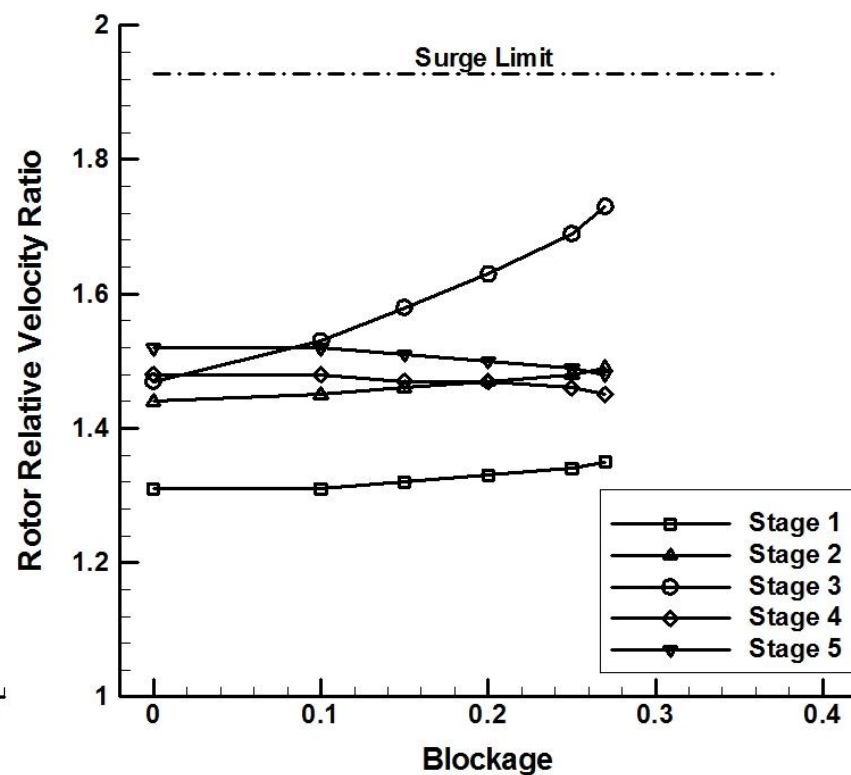
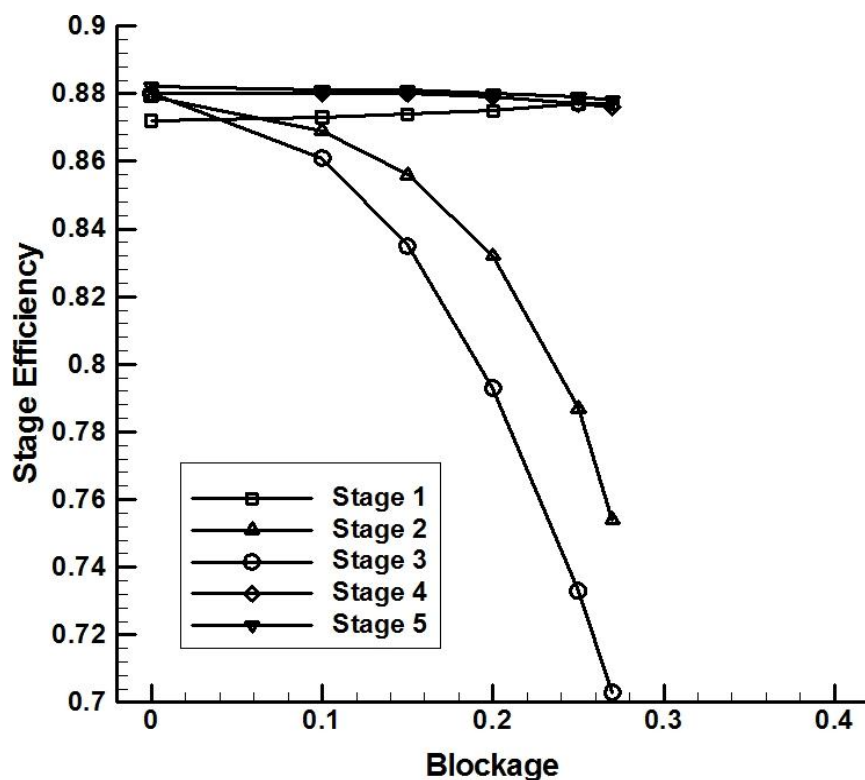
Effect of Additional Blockage in LPC on Turbine Inlet Temperature; from Baseline





Effect of Additional Blockage on Stage Efficiency and Rotor Relative Velocity Ratio, Blockage in Stage 2

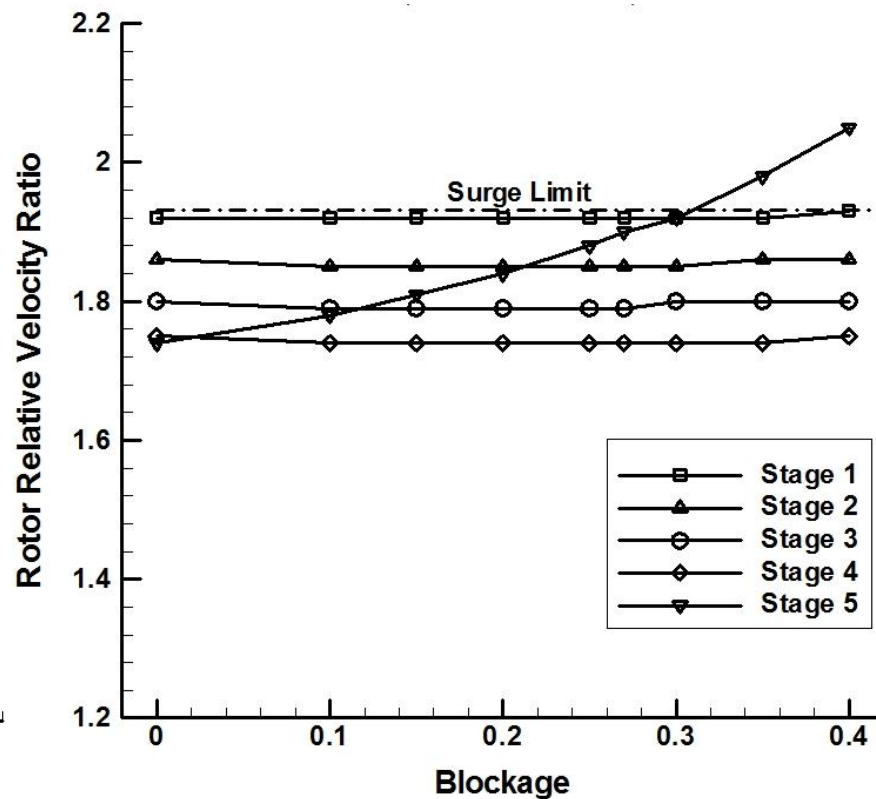
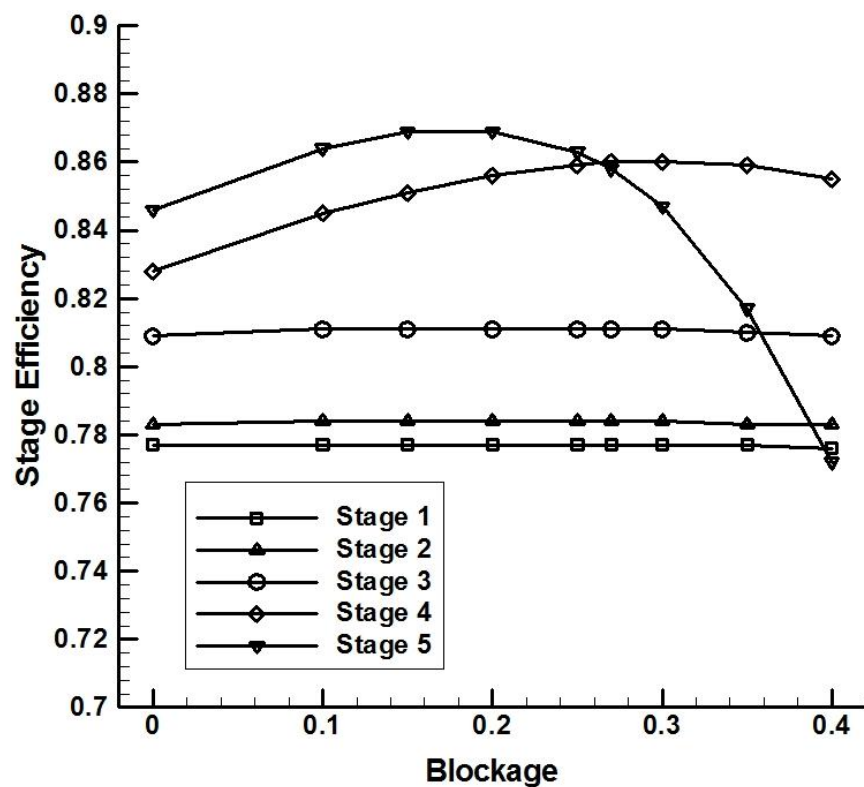
Inlet Mach .78, Altitude 35K ft, Thrust 75.6%





Effect of Additional Blockage on Stage Efficiency and Rotor Relative Velocity Ratio, Blockage in Stage 4

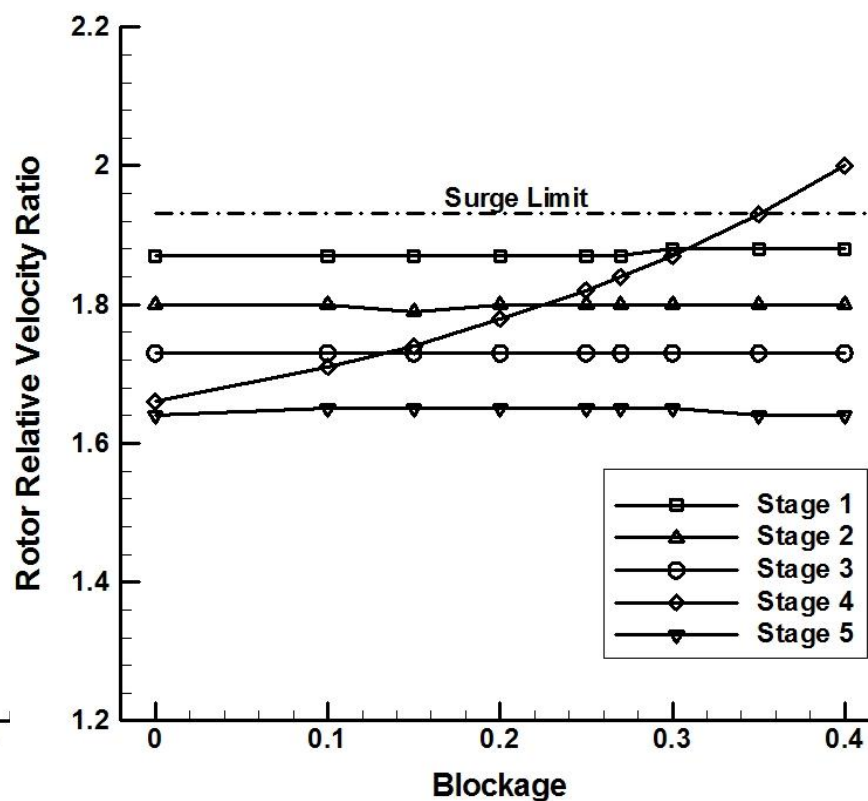
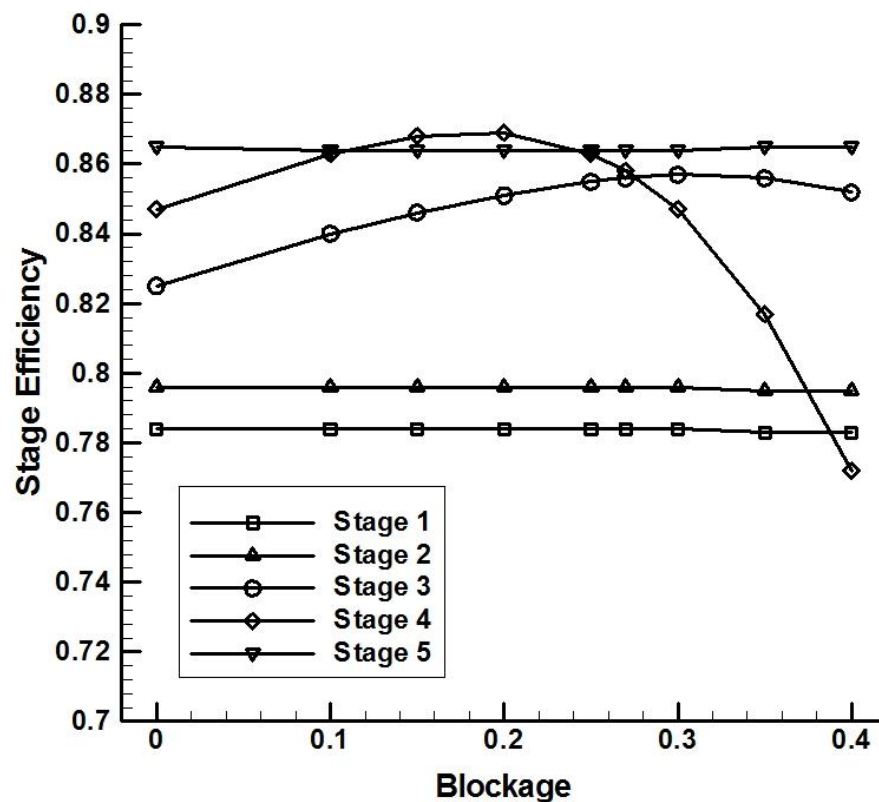
Inlet Mach .73, Altitude 38K ft, Thrust 10%

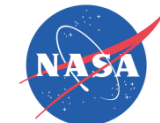




Effect of Additional Blockage on Stage Efficiency and Rotor Relative Velocity Ratio, Blockage in Stage 3

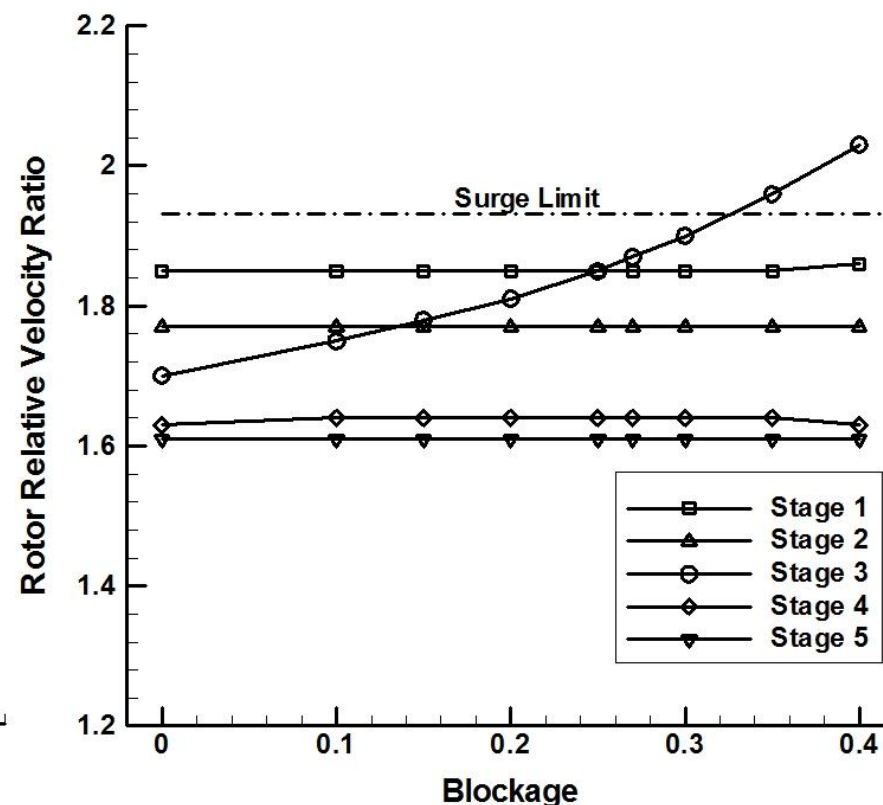
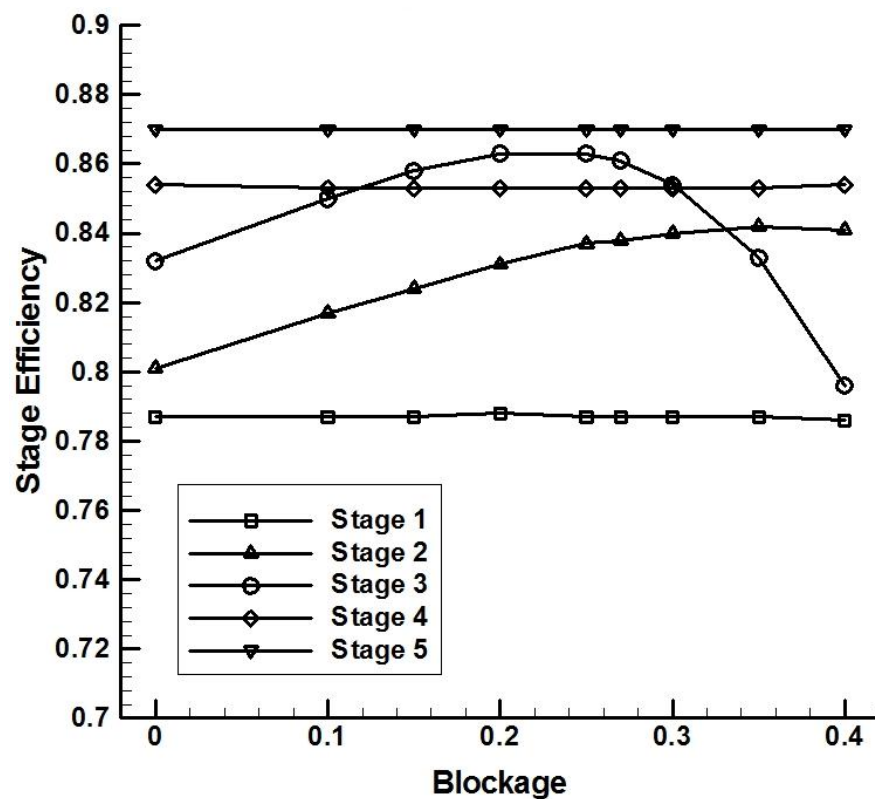
Inlet Mach .55, Altitude 25K ft, Thrust 10%





Effect of Additional Blockage on Stage Efficiency and Rotor Relative Velocity Ratio, Blockage in Stage 2

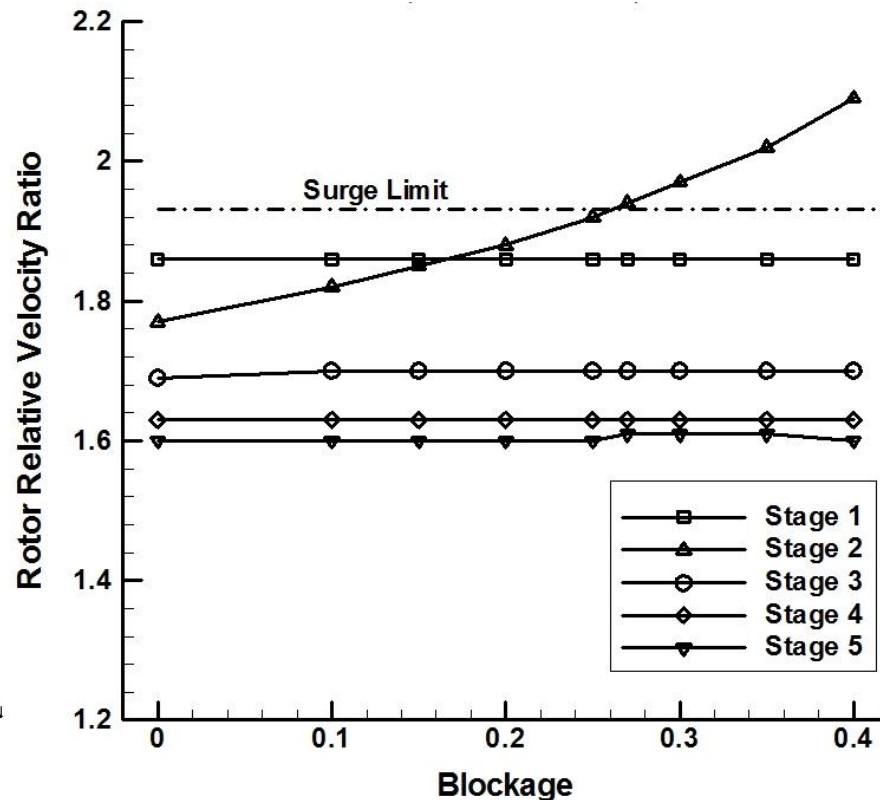
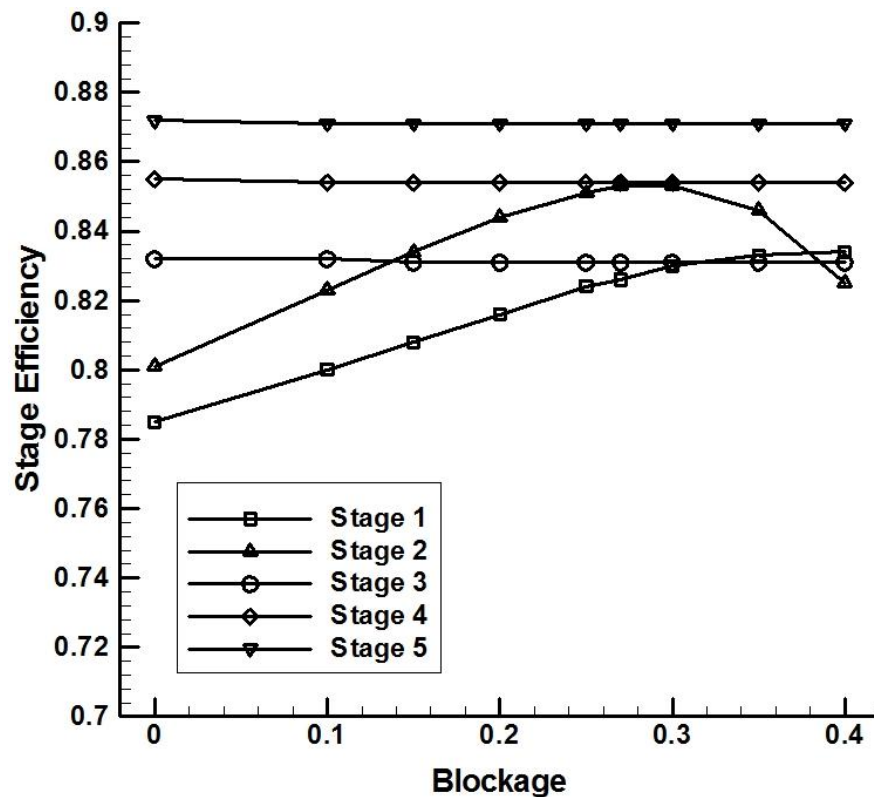
Inlet Mach .49, Altitude 20K ft, Thrust 10%





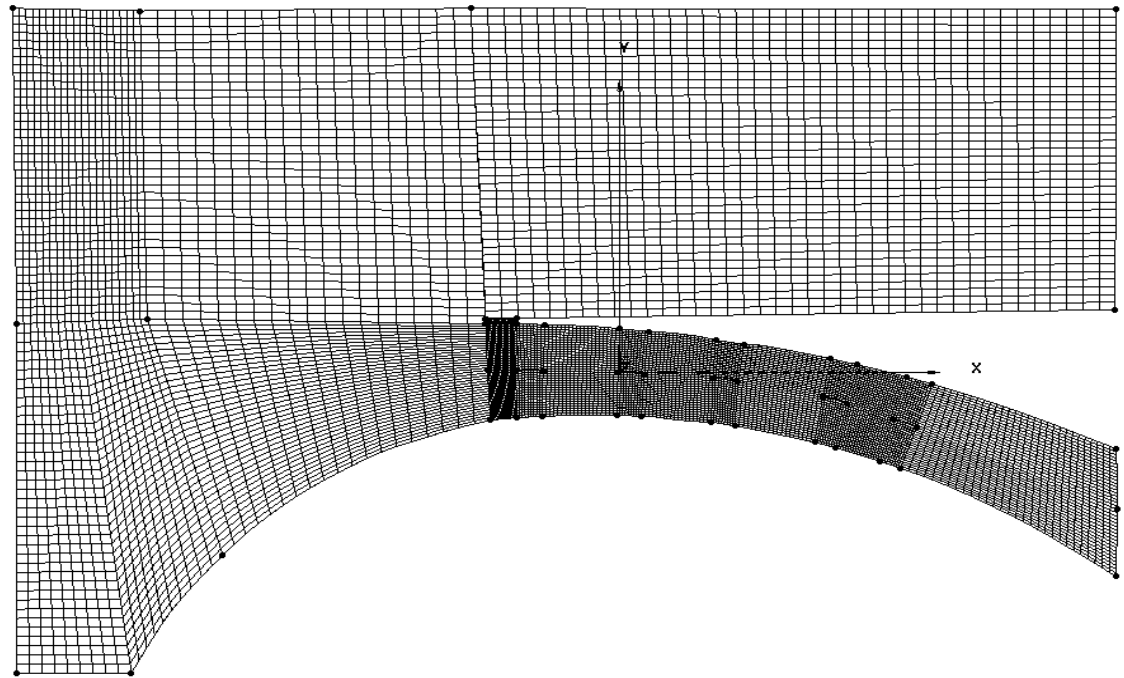
Effect of Additional Blockage on Stage Efficiency and Rotor Relative Velocity Ratio, Blockage in Stage 1

Inlet Mach .45, Altitude 15K ft, Thrust 10%



Estimation of Ice Accretion

Computational Grid of
Fan and LPC for analysis
with GlennICE Accretion
Code



The blade-row by blade-row flow field estimated by the NPSS - COMDES is provided to the GlennICE code for refined estimation of ice accretion.

To be continued in the following session on “Engine Icing Accretion Simulation”.



Summary and Conclusions

- A computational tool is being developed to estimate effects of compressor stator vane ice accretion on the performance of the LPC in an engine system environment.
- The current tool consists of an engine thermodynamic cycle model, and a compressor mean line flow analysis model.
- The engine system model and the compressor flow analysis models have been tightly coupled.
- The tool has been applied to a notional gas turbine engine to parametrically assess the sensitivity of engine performance to blockage due to ice accretion. The analysis was conducted over a flight trajectory typical of a commercial aircraft.
- The assumption of static temperature alone as an early indicator of the onset of ice accretion is not sufficient by itself. A model based on relative humidity and wet bulb temperature may be necessary for an improved early estimation of initiation of ice accretion.